10/10: Excellent. Well written and well described.

[redacted]

Research Paper Review #1

Article:
H. Berestycki, O. Diekmann, C.J. Nagelkerke and P.A. Zegeling. Can a Species Keep Pace with a Shifting Climate? B. Math. Biol. (2008) 71: 399-429. DOI: 10.1007/s11538-008-9367-5. http://link.springer.com/article/10.1007/s11538-008-9367-5

Abstract: Consider a patch of favorable habitat surrounded by unfavorable habitat and assume that due to a shifting climate, the patch moves with a fixed speed in a one-dimensional universe. Let the patch be inhabited by a population of individuals that reproduce, disperse, and die. Will the population persist? How does the answer depend on the length of the patch, the speed of movement of the patch, the net population growth rate under constant conditions, and the mobility of the individuals? We will answer these questions in the context of a simple dynamic profile model that incorporates climate shift, population dynamics, and migration. The model takes the form of a growth-diffusion equation. We first consider a special case and derive an explicit condition by gluing phase portraits. Then we establish a strict qualitative dichotomy for a large class of models by way of rigorous PDE methods, in particular the maximum principle. The results show that mobility can both reduce and enhance the ability to track climate change that a narrow range can severely reduce this ability and that population range and total population size can both increase and decrease under a moving climate. It is also shown that range shift may be easier to detect at the expanding front, simply because it is considerably steeper than the retreating back.

Review:
1. What is the problem being discussed?
This article addresses the phenomenon of climate change, particularly in temperature. As the local climate shifts to the north or to the south, the species which lives within that zone must migrate with their preferred local climate. If they are not able to keep up with the climate shift, they will become abandoned in an unfavorable environment and face extinction. This study addresses the size of the land area which is shifting and how that affects the probability of survival, as well as the diffusion speed of the species across the land.

2. What has been done before by this and/or other authors?
One of the authors, C.J. Nagelkerke has already published material on this subject using simulations. The simulations focused on the transient conditions immediately after the advent of climate shift, whereas this publication focuses on long-term results. Other authors, such as Okubu and Levin (2001) studied a similar subject they referred to as the "critical patch problem," though they did not study the issue quantitatively. The most similar study that has been conducted was by Potapov and Lewis in 2004. The two studies differ only by Potapov and Lewis' analysis of two competing species, how they are impacted by a shifting climate, and how that additional stress affects the chances of one of the species' survivals. In this publication, only one species is analyzed. The authors of "Can a Species Keep Pace with a Shifting Climate" also claim that their study contains more biological insight than the former studies.

3. What do these authors do that is new? Summarize the main results.
Unlike C. J. Nagelkerke's former research, the new publication focuses on obtaining results analytically, in order to verify Nagelkerke's simulated results. Through simplified models of the reaction-diffusion equation, the authors are able to determine the critical size of the preferred local climate in order to sustain the life of the species within. They were also able to determine that, when the local climate is shifting north, the population curve of the northern front is much steeper than the southern end, and that therefore, the maximum population density exists closer to the northern side of the favorable area. The sharpness of the northern front represents those members of the population that are leading the migration. The flatness, or bluntness, of the southern end depends on how harsh the unfavorable climate is and how

long the species can continue to survive there before migrating. Their third conclusion was that the rate of survival of a population depends on how fast the climate is shifting. When the climate shift is very slow, the population may actually grow while migrating. This is because while migrating, the species is given new, untouched land with fresh resources to colonize. However, if the climate shift begins too quickly, extinction is more likely to occur. Most often, there is a combination of these two outcomes, and the authors have created an equation which determines which of the two, either survival or extinction, is most prevalent.

Based on this algorithm, the slower decay of the southern end of the hospitable territory and the steeper slope of the northern end gives the species more land to occupy while continuing to exist in the old territory for a short period of time. This can increase the population growth of the species because they have more resources available. However, if the speed of climate shift suddenly sped up without an immediate increase in migration speed, the result would be rapid extinction. This is because so many members of the population lingering at the southern end would suddenly be trapped in the uninhabitable area.

In order for the species to persist, the births amongst the population in the preferred habitat must counterbalance the deaths that occur naturally within the preferred habitat and the deaths that occur because members of the population fell behind. Therefore, the population must migrate at the same speed as the climate shift in order to minimize the number of those that are left behind in inhospitable environments.

4. What tools do they use to address the problem, e.g., field studies, lab experiments, data analysis, mathematical model development, computer simulation, mathematical analysis? How do they use these tools?

This study was conducted using a mathematical model of one species migrating during a climate change, using a reaction-diffusion equation. The authors use linearization in order to compute the eigenvalues of their system of two equations. They then analyze these eigenvalues in order to form a phase-plane diagram that shows the stability of the equilibrium points of the migrating species. For instance, in Figure 2, the equilibrium point that represented extinction was stable, while survival was unstable.

The authors are able to plot relationships between the length of the hospitable environment, the speed at which that environment is moving, and the diffusion rate at which the population must move in order to keep up. They use numerical analysis to show the relationship between climate shift speed and the sharpness of the population density curve at the northern front, and how that corresponds to the bluntness of the southern end.

5. Select one important figure and summarize what it describes and what is its significance.

Figure 5 is a graph of the critical length, L_{crit}, or length of the preferred environment, versus the diffusion coefficient, D, of the population. The graph plots this relationship for several speeds of climate shift, c. Each of these lines exhibits a pattern similar to exponential decay. This is because as L_{crit} decreases, the suitable area for the species shrinks and the diffusion coefficient of the species across the territory must increase in order for them to survive. As long as the species is migrating quickly, they can survive on a small area of land. It is also notable from Figure 5, that as c increases, the diffusion coefficient is much greater than that of lower c speeds for the same critical lengths. This is because the species must diffuse across land much faster in order to migrate at the same speed as the shifting climate.

6. What are the open questions and/or what is their plan for the future?

The authors of this article admit that their analysis was relatively simple, since they only used a one-dimensional spatial domain –only looking at one species. Adding more dimensions, or more species, would create much more complex results, and more nuanced biological insights. They reference Berestycki and Rossi (2008) as a source for a two-dimensional analysis. The authors were also unable to study the effect of migration shape on a population's ability to survive: for instance, if the population density of the species bottlenecks in the middle of the population. They plan to study this possibility and other migration geometries in future works.